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Wind energy resource development in Ethiopia as an alternative energy future beyond the dominant hydropower

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ABSTRACT

Over the centuries, energy has been supplied by wood, coal, oil and natural gas, as well as by uranium. All these energy sources are limited and create pollution problems. This has led countries to focus on a sustainable and cleaner energy sources. Wind energy is rapidly emerging as one of the most cost-effective forms of renewable energy with very significant increases in annual installed capacity around the world. In this paper, authors have tried to review the current state of wind power utilization in Ethiopia. First, a brief overview is given on the Ethiopian electric power sector in order to gain insight into the main energy sources of the country and installed electric power capacities. Wind energy potential and current energy policy in Ethiopia were discussed respectively in the subsequent sections. Finally, short reviews of the ongoing and planned wind energy together with other renewable energy projects are given. Ethiopia, a country that relies on hydroelectric plants for the bulk of its power, is now developing significant wind energy capacities. Lack of reliable wind data covering the entire country has been one of the reasons for limited application of wind energy in Ethiopia, but recently studies have shown that Ethiopia has substantial potential to generate electricity from wind, geothermal and hydropower. Considering the substantial wind resource in the country, the government has committed itself to generate power from wind plants by constructing eight wind farms with total capacities of 1116 MW together with a number of hydropower plants over the five year Growth and Transformation Plan (GTP) period from 2011 to 2015. This development of wind power is a part of the current energy sector policy of the country that aims at a five-fold increase in renewable energy production by the end of 2015.

Contents

1. Introduction

Energy prices, supply uncertainties, and environmental concerns are driving the developed nations to rethink their energy mix and develop diverse sources of clean, renewable energy. Most of the developed countries are working toward generating more energy from domestic resources that can be cost-effective, and replaced or "renewed" without contributing to climate change or major adverse environmental impacts. Wind power, as an alternative to fossil fuels, is growing at the rate of 30% annually, with a worldwide installed capacity increased from 196,653 MW in 2010 to 239,000 MW at the end of 2011 [1]. The amount generated in

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2011 was enough to cover 3% of world's electricity demand [1]. Wind power is widely used in Europe, Asia, and the United States. China, United States, Germany, Spain and India respectively are top five countries in terms of installed cumulative capacities at the end of 2011 [2,3].

Wind power is capable of becoming a major contributor to the developing nations of Africa. According to 2011 Global Wind Energy Council (GWEC) statistics, all wind turbines installed in Africa had a capacity of 993 MW. Egypt was leading the continent with installed capacity of 550 MW followed by Morocco and Tunisia each with installed capacity of 291 MW and 114 MW respectively [3]. Those three countries had 96% share of total installed capacity of wind power in the continent at the end of 2011. The other African countries had only 4% share (38 MW) of the total installed capacity by the same year [3]. Egypt also targets to reach 7500 MW by 2020 [4] where as Morocco planned to make the current capacity 2000 MW by the same year. Other promising countries in Africa include Ethiopia, Kenya, Tanzania and South Africa, where wind project development is firmly underway [5].

In this paper, authors have made an effort to review the current state of wind power utilization in Ethiopia. Ethiopia, one of the fastest growing countries in the sub Sahara African region that relies on hydroelectric plants for the bulk of its power, is now turning to wind energy. The government has committed itself to generate power from wind plants by constructing eight wind farms over the five year growth and transformation plan (GTP) period from 2011 to 2015 [6]. Currently, four wind farms are under construction and one wind farm with capacity of 52 MW power already completed in December 2012. Lack of organized data on the energy potential of the country covering the entire regions has been one of the reasons for limited application of wind energy in Ethiopia, but recently wind energy resources of the country were identified in several regions of the country.

In this article, first, a brief overview is given on the Ethiopian electric power sector in order to see the main energy sources of the country and installed electric power capacities. Wind energy potential and current energy policy in Ethiopia were discussed in subsequent sections. Finally, short reviews of the ongoing renewable energy resources such as wind, geothermal and hydropower projects are given with conclusions.

2. Energy sector in Ethiopia

Having total area of 1,104,300 km^2, 163 billion cubic meters of water resource per annum and 82,101,998 populations in the Horn of Africa, Ethiopia is often referred to as the water tower of Africa [7]. Ethiopia has an enormous potential for hydropower developments, next to Democratic Republic of Congo in Africa, with generating capacity of about 45,000 MW from hydropower plants [7,8]. In addition, Ethiopia has a capacity of generating more than 5000 MW from geothermal and 10,000 MW from wind [8]. Estimates of other renewable resources are also substantial. Located in the tropics, Ethiopia receives high solar energy, with an average potential of 5.26 kWh per square meter per day. Exploitable natural gas, coal and renewable energy potential of Ethiopia are given in Table 1 [7,8].

Even though Ethiopia is endowed with all sources of energy such as hydro, solar, wind, biomass, natural gas, geothermal, etc., it has not been able to develop, transform and utilize these resources for optimal economic development. The current total deployment is limited to 2052 MW (52 MW is added from wind in December 2012) [8].

The Ethiopian Electric Power Corporation (EEPCo) was established in 1997 after serving in the name of Ethiopian Electric Light and Power Authority (EELPA) which was founded in 1956 [8]. EEPCo is responsible for generating, transmitting, distributing and selling of electric energy throughout the country.

The corporation has two electric energy supply systems. These are the Inter Connected System (ICS) and the Self Contained System (SCS). Hydropower plants are the main energy source of ICS. The SCS consists of mini hydropower plants and diesel power generators allocated in various areas of the country [8]. The current capacity of Ethiopian Electric Power Corporation both in ICS and SCS systems by the end of 2011 is given in Table 2.

The capacity of EEPCo by the end of 2011, were as follows: 1848.75 MW in hydropower plants, 142.82 MW in Diesel and 7.30 MW in geothermal power plant which totaled 2000 MW as can be seen in Table 2. With annual energy production of 4980.08 GWh and 5866 electrified towns and rural villages; still the electric energy access of the country is limited to 46%, which is insufficient to meet the country's economic needs. In addition, this figure is not reflecting the number of the population who are actually using electricity. The official estimation, 46%, is calculated by the population living in the electrified area. The actual access rate of the population that is using electricity is expected to be lower since many of the poor do not have financial resource to pay the cost for distribution lines from the national grid to their houses. Although it is still low, the access to energy is gradually improving from 16% in 2005 to 20% in 2007 and it was expected to reach 50% by the end of 2012 from the 46% in 2011 [8,9]. With the addition 52 MW from wind in December 2012, the current electric energy access of the country is around 50%. The Ethiopian government is devoted to improve its energy production capacity as quickly as possible by constructing new power plants and expanding the national grid. The country has planned to reach 10,000 MW of installed capacities by 2015 [9].

Inter-Connected System (ICS): by the end of 2011, the ICS consists of 11 hydropower plants, 13 diesel power plants and one geothermal power plant with total installed capacity of 1842.60 MW, 112.3 MW and 7.30 MW respectively. ICS generation plants and their capacities are given in Table 3 [8].

Self-Contained System (SCS): the SCS consists of three small hydropower plants and several diesel power plants. Generation in this system is mainly by diesel power plants having an aggregate capacity of 36.87 MW by the end of 2011. The contribution from the small hydropower plants is only 6.15 MW despite the availability of many small rivers and waterfalls that could be used for electricity

Table 1
Exploitable potential of energy resources in Ethiopia [7,8].

No	Resource	Unit	Exploitable potential
1	Biomass	Million metric ton/year	75
3	Hydropower	MW	45,000
4	Solar	kWh per meter square per day	5–6
5	Wind	MW	10,000
6	Geothermal	MW	5000
7	Natural Gas	Billion cubic meter	113
8	Coal	Million toe	400

Table 2
Capacity of EEPCo [8].

No	Capacities	Amount
1	Installed capacity of power plants (MW)	2000
2	Annual energy production (GWh)	4980.08
3	Gross consumption (GWh)	3844.87
4	Length of distribution network (km)	138,838
7	Number of customers (Million)	1.9
9	Electricity access rate (%)	46

generation to supply many off-grid rural areas in Ethiopia. SCS generation plants and their capacities are given in Table 4 [8].

As can be seen from Tables 3 and 4, 98.2% of the generated energy comes from the ICS system while remaining 1.8% is from SCS. Looking on the share of total installed capacity of the country's power plants, only 7% of the total generated energy comes from Diesel; the rest is from clean renewable energy resources with 92.7% from hydropower plant and 0.3% from a geothermal plant. The total installed capacity, energy production and gross consumption between 2004 and 2011 are shown in Figs. 1 and 2 respectively [8].

As mentioned above, currently most of the generated energy comes from hydropower plants. This trend has been the same since the establishment of EEPCo. Total energy production and percentage share of hydropower from 1971 to 2011 are given in Figs. 3 and 4 respectively [8,10].

The value for electricity production from hydroelectric sources in Ethiopia was 4930 GWh in 2010/2011. Over the past 40 years this indicator reached a maximum value of 4930 GWh in 2010/2011 and a minimum value of 304 GWh in 1971 as it is shown in Fig. 3. When we look on share of electricity production in the Fig. 4, from hydroelectric sources, percentage of total in Ethiopia was 92.7% as of 2010/2011. Its highest value over the past 40 years

Table 3
ICS generation plants and their capacities [8].

	Name	Capacity (MW)				
		Hydro	Diesel	Geothermal	Total	In service date
1	Koka	43.20			43.20	1960
2	Awash II	32.00			32.00	1966
3	Awash III	32.00			32.00	1971
4	Finchaa	134.00			134.00	1973
5	Melka Wakena	153.00			153.00	1988
6	Tis Abay I	11.40			11.40	1964
7	Tis Abay II	73.00			73.00	2001
8	Gilgel Gibe I	184.00			184.00	2004
9	Tekeze	300.00			300.00	2009
10	Gilgel Gibe II	420.00			420.00	2010
11	Tana Beles	460.00			460.00	2010
12	Aluto Langano			7.3	7.30	1999
13	Kaliti		14.00		14.00	2004
14	Dire Dawa		38.00		38.00	2004
15	Awash 7 Killo		35.00		35.00	2004
16	Other ten diesel plants		25.30		2.30	1958
	ICS Sub Total	1842.60	112.3	7.3	1962.2	

Table 4
SCS generation plants and their capacities [8].

	Site	Capacity (MW)			
		Hydro	Diesel	Geothermal	Total
1	Yadot	0.35			0.35
2	Sor	5.00			5.00
3	Dembi	0.80			0.80
4	Isolated diesel power plants		30.52		30.52
	ICS Sub Total	6.15	30.52		36.67

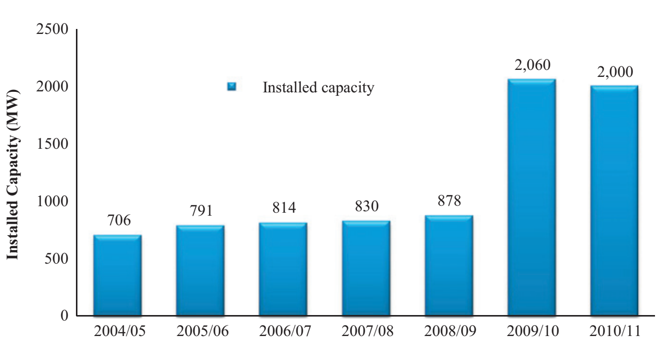

Fig. 1. Installed capacity of EEPCo for the last seven years [8].

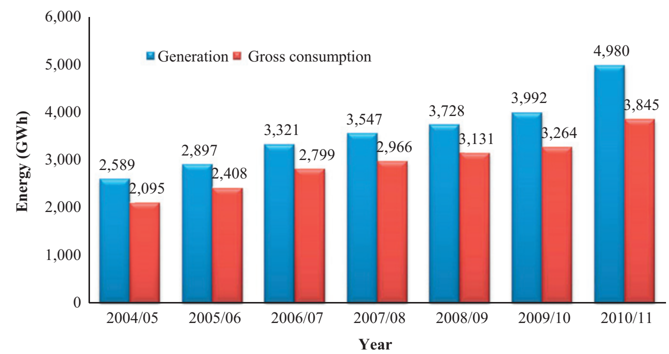

Fig. 2. Electricity generation and gross consumption in Ethiopia for the last seven years [8].

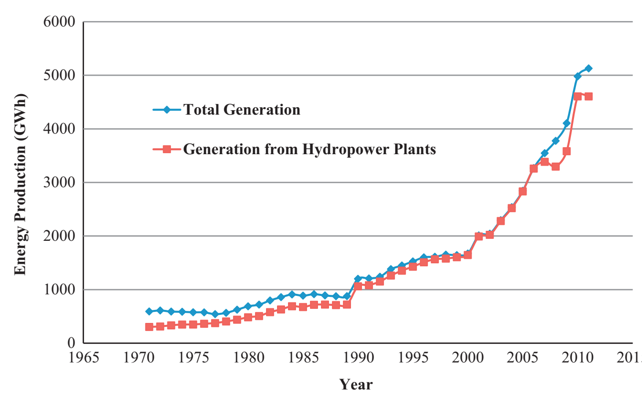

Fig. 3. Total energy production and generation from hydropower plants from 1971 to 2011 [8,10].

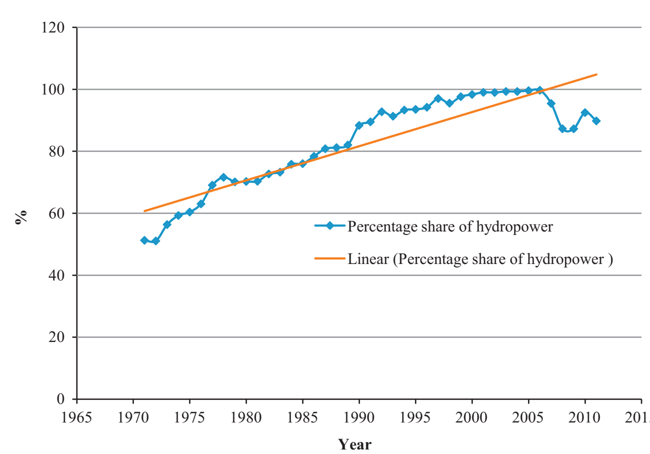

Fig. 4. Percentage share of electricity production from hydropower plants from 1971 to 2011 [8,10].

was 99.69% in 2006, while its lowest value was 51.06% in 1972 [8,10].

The per capita energy consumption in Ethiopia by the end of 2011 has been about 60 kWh/year, which is much lower than the average minimum level, 500–1000 kWh/yr, for reasonable quality of life [11]. The electricity loss in the country is about 20%, which is much higher than the international average, 12–13.5% [12]. According to EEPCo most of the loss attributed to distribution from the national grid to end users. Currently, the Ethiopian government is financing projects to promote efficiency and automation of distribution. EEPCo has planned to reduce the energy loss from the current level of 20% to the international average, 13.5%, by the end of 2015 [9].

As can be seen from the previous figures and tables, the Ethiopian energy sector is one of the least developed in the world. At present, the country is heavily dependent on traditional fuels consisting mainly of wood and crop residues. The low level of energy consumption is paralleled by limited use of electricity. Without access to modern energy services, the poor people in the country will not be able to grow beyond subsistence level. Access to modern energy supply makes it possible to improve living conditions substantially, through the development of modern agricultural production modes. It also enables the state to offer education, health and communication services at lower cost and in greater quality. It also encourages the dissemination of information, an essential factor in political decision making.

Knowing those facts, in recent years, the Ethiopian government has committed itself to utilize the substantial wind power resource together with the abundant hydropower. According to the growth and transformation plan (GTP) adopted by the government for the period of 2011 to 2015 [6], EEPCo has planned to build eight wind farms together with one geothermal plant and a number of hydroelectric projects, including the 1870 MW Gilgel Gibe III dam on the Omo River and the 6000 MW Grand Ethiopian Renaissance Dam on the Blue Nile river [9]. Currently, four wind farms are under construction and one wind farm with capacity of 52 MW power already completed in December 2012. Those renewable energy projects are parts of EEPCo's plans to increase national electricity generation capacity five times by 2015, from a current 2052 MW (52 MW added from wind in December 2012) to about 10,000 MW [9].

Increasing electricity generation, in turn, is the key to the government's broader economic development plans. The Ethiopian government is keen to advance its electricity generation capacity as quickly as possible and is also investigating the country's renewable energy potential. Currently, the Ministry of Water & Energy (MoWE) is working on a project designed to produce a comprehensive and updated energy sector data set for the entire country [7]. This implies the country is on the way to have its first National Energy Map which will enable it to attract investors to engage in the sector by indicating clearly the potential areas for power generation.

3. Wind energy potential in Ethiopia

Wind data has been collected and documented by National Meteorological Service Agency (NMSA) primarily for a purpose of aviation. This data is not of much use for estimation of the wind energy potential as most of the meteorological stations in the country do not fulfill the required standard for wind speed measurements. According to NMSA, most of the meteorological

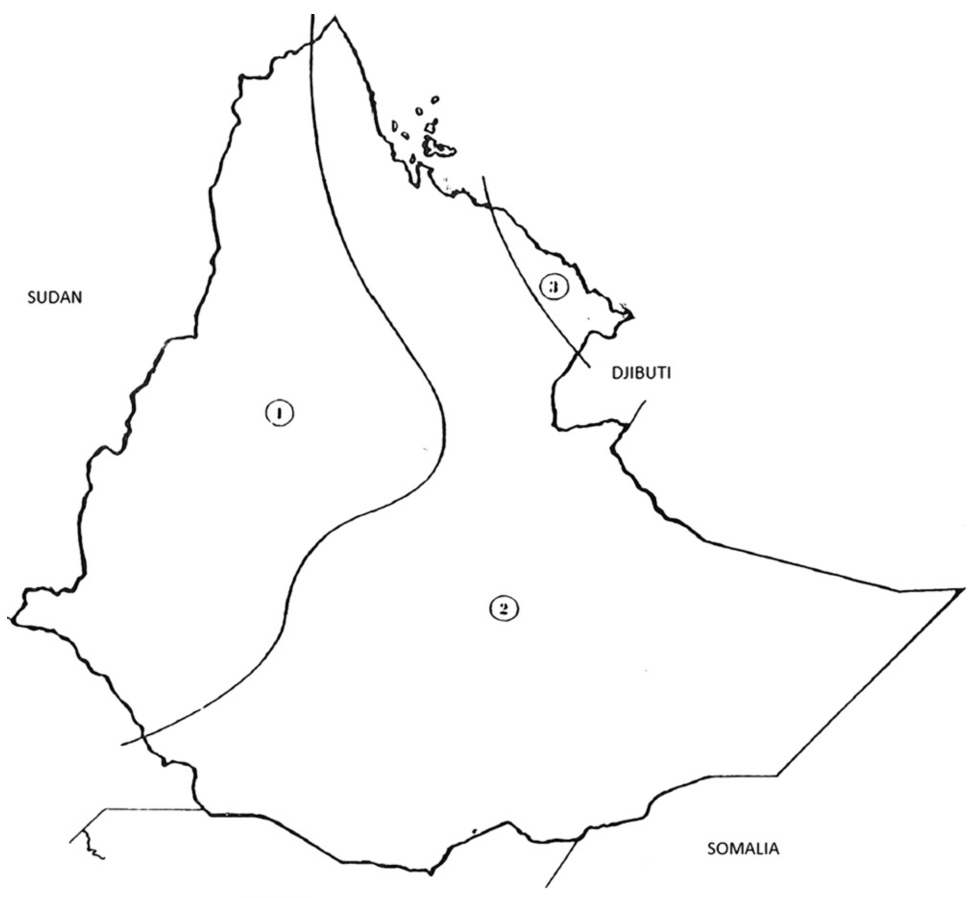

Fig. 5. Wind Regions of Ethiopia as estimated by CESEN-ANSALDO Group [14].

station measurements for wind speed were taken at heights lower than the accepted standard of 10 m and over half were taken at just 2 m above ground level. So far few studies on the wind energy resource assessment at national level in Ethiopia were conducted to estimate wind energy potential of the country. Those studies are reviewed below.

The first national level wind energy potential estimation has been done by Italian company CESEN-ANSALDO Group in mid 1980s [13]. However this estimation was based on theoretical analysis with only very few ground data measurement stations. Low density of station measurements could not allow a greater geographical resolution. The estimation by CESEN categorized the wind regions in Ethiopia only in three very broad groups, an increasing gradient in wind speed from west to east with maximum concentration near Djibouti boarder on the Red Sea Coast Fig. 5 [14].

According to the study by CESEN-ANSALDO Group, including Eritrea, Table 5 shows the regions with annual mean wind speed and annual mean wind energy density estimated at 10 m above ground level.

Table 5
Annual mean wind speed and wind energy density at 10 m estimated by CESEN [14].

	Annual mean wind speed (m/s)	Annual mean wind energy density (W/m^2)
Region 1	3.5	< 63
Region 2	3.5–5.5	63–190
Region 3	5.5	> 190

The second national level study of wind energy resource in the country was conducted in 2007 by Solar and Wind Energy Resource Assessment (SWERA) [15], a program sponsored jointly by the United Nations Environmental Program (UNEP) and The Global Environment Facility (GEF). Mesoscale model approach was used to develop a wind speed map for Ethiopia [16]. Mesoscale models generally use a grid size of between 2.5×2.5 km^2 and 250×250 km^2. All models using smaller (more accurate) grid sizes are called 'micro-scale' models. The principle of mesoscale models is to calculate the wind vectors in three dimensions (3D) for the complete reference area.

SWERA used data sets such as meteorological data from NMSA, measured data from few stations and modeled ocean winds derived from satellite data. Numerical simulations and wind resource data generation of the SWERA project was done based on the Risoe model, Risø DTU National Laboratory for Sustainable Energy which used the Karlsruhe Atmospheric Mesoscale Model

Table 6
Classification of wind resource and extent of associated land areas [15].

Wind resource category	Wind class	Wind power density (W/m^2)	Wind speed at 50 m (m/s)	Total area (km^2)
Poor	1	50–200	3.5–5.6	564,606
Marginal	2	200–300	5.6–6.4	96,801
Moderate	3	300–400	6.4–7.0	42,935
Good	4	400–500	7.0–7.5	23,975
Excellent	5	500–600	7.5–8.0	6529
Excellent	6	600–800	8.0–8.8	3814
Excellent	7	Above 800	Above 8.8	1715
Total area covered by Poor-to-Excellent wind regions				740,376

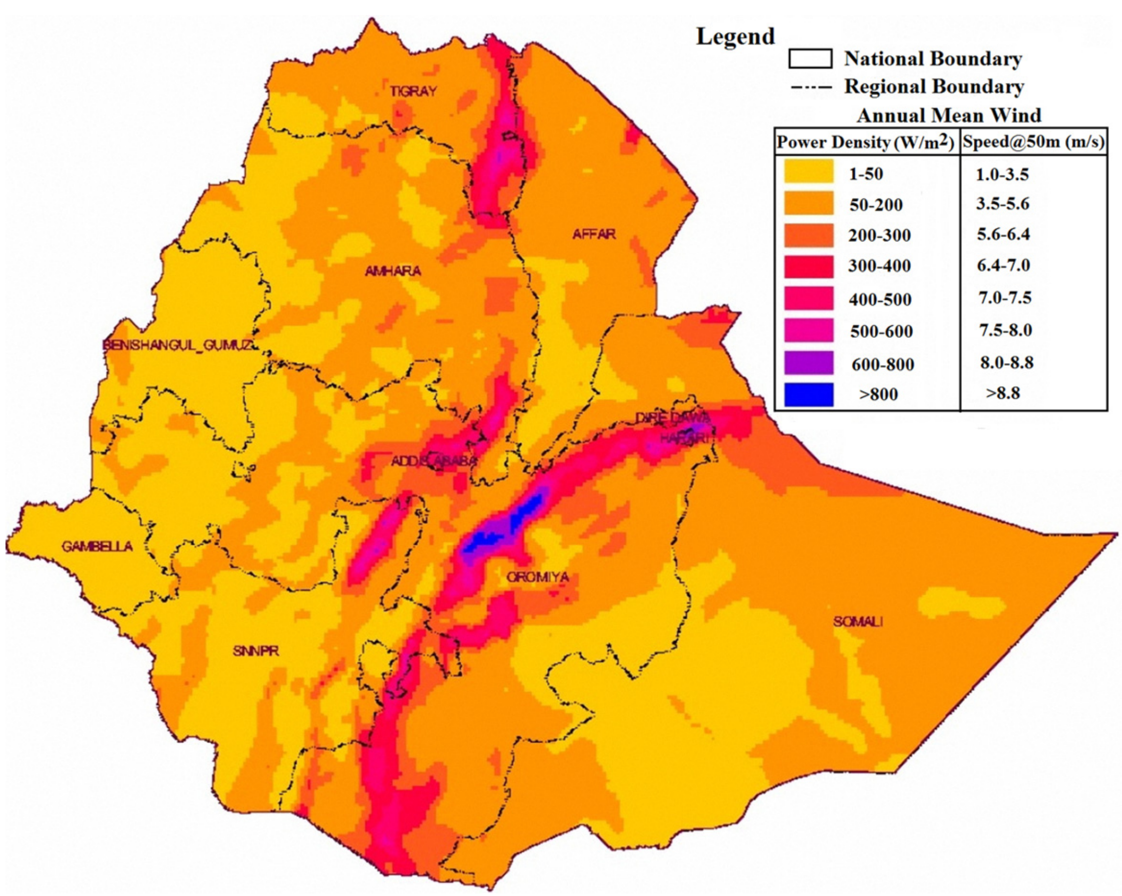

Fig. 6. Annual mean wind power density of Ethiopia at 50 m height without excluding protected areas [17].

(KAMM) [16] on a 10 km grid size. That means the results do not account for local influence on scales below the grid size.

Like the wind velocity estimations made by CESEN, the accuracy of the SWERA wind data also suffers from low density of wind measurement stations used. Based on the SWERA wind resource data, a GIS map was generated to indicate the annual mean wind power density of any particular location in Ethiopia. The wind atlas also helps to spot locations with poor-to-excellent wind resources as a first estimation. As recommended by SWERA, further ground measurement is necessary for verification of the estimation when planning a deployment of wind turbines on a site. The wind regions of the country were classified into seven categories and the area under each category is calculated and presented at regional level indicating suitable areas for various purposes of wind development.

A hierarchical approach was used for the estimation of the wind resource where unsuitable areas are gradually eliminated. Starting with identification of the resource at various wind categories, from poor to excellent wind regimes, land areas available under these categories were mapped irrespective of their land use. Further screening was applied by eliminating designated and inaccessible areas, applying environmental and economic considerations, and taking areas with wind speed estimates above a threshold value.

The first estimation considers the whole land area of the country that practically fall under various wind resource categories without excluding land areas that could possibly be eliminated for reasons of accessibility, economics or environmental. This first estimation provides the bigger picture of the country in terms of locating windy areas. The practicable potential is certainly lower than the first estimation as more land will be eliminated with further screening. A GIS map showing geographic distribution of wind resources of Ethiopia without excluding protected areas is given in Fig. 6 [17].

The classification of the wind resource in terms of annual mean wind speed and power density corresponding to those shown in the Fig. 6 are presented in Table 6. Table 6 also shows land areas of the country that fall under those wind resource classifications without excluding preserved areas.

The above estimation of the wind resource does not take account of the restrictions due to the availability of infrastructure such as electricity grid and road networks. Considering this fact geographic distribution of wind resources favorable for grid based wind electricity generation is given in Fig. 7 [15].

The wind map in Fig. 7 shows all wind regions that overlap with a buffer zone of existing and planned high voltage transmission lines and all roads excluding protected areas, forest lands and water bodies. The map also shows that the grid and road networks matches well with the high wind resource areas. Areas with wind resource favorable for grid based wind electricity generation are given in Table 7.

In addition to the study conducted by SWERA in 2007 and CESEN-ANSALDO Group in 1986; currently the MoWE is

Table 7
Categories of wind resource favorable for grid based wind electricity generation [17].

Wind resource category	Wind class	Wind power density (W/m^2)	Wind speed at 50 m (m/s)	Area (km^2)	Gross capacity (MW)
Excellent	7	> 800	> 8.8	401	2005
Excellent	6	600–800	8.0–8.8	985	4925
Excellent	5	500–600	7.5–8.0	3729	18,645
Good	4	400–500	7.0–7.5	15,175	75,875
Total (Good to Excellent)				20,290	101,450

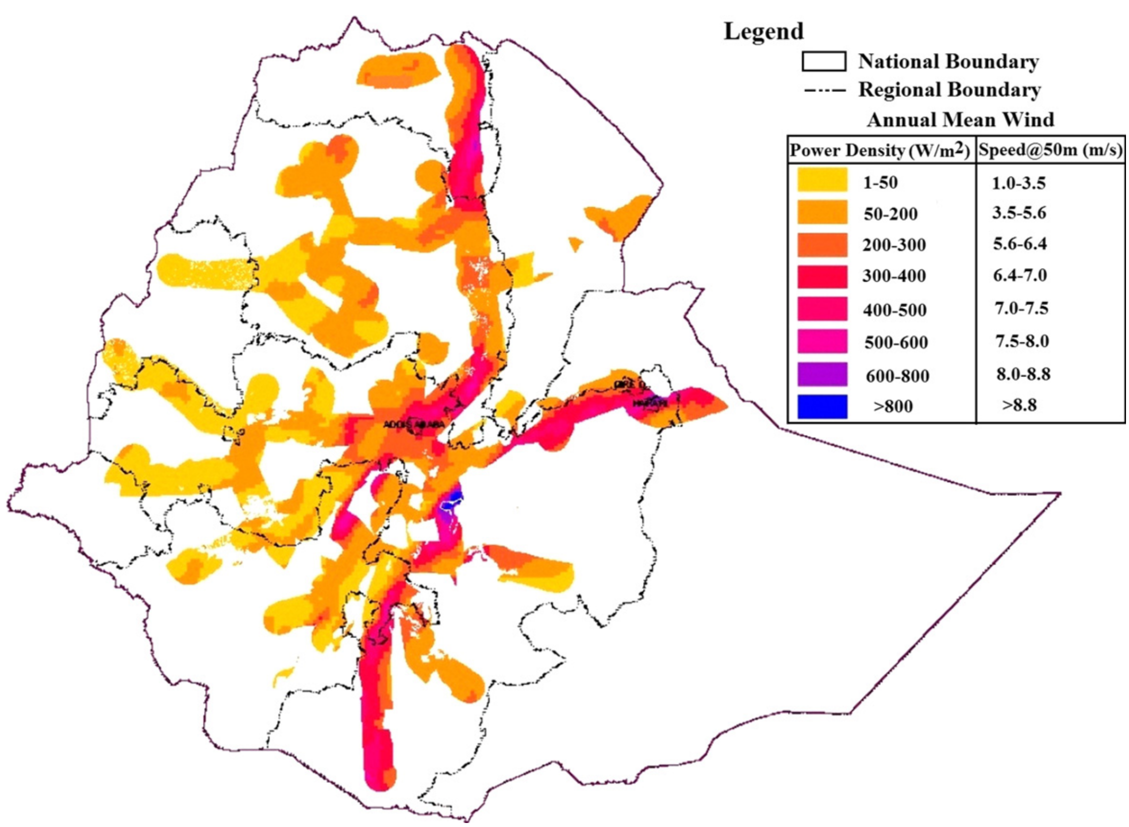

Fig. 7. Geographic distribution of wind resources favorable for grid based wind electricity generation [15].

conducting a study on energy potential at national level not only for wind resource potential but totally comprehensive and updated energy sector data estimation. The study is initiated by the MoWE in May 2010 [18]. The project, titled the 'Energy Sector Mapping & Database Development (ESMAD)' was conducted by a company Professional Consulting on Energy & Development, (PROCEED) as a lead consultant with eight private senior consultants [7]. The first phase, which took 16 months, developed a web based and Geographical Information System (GIS) enabled energy database and it was overseen by a national steering committee in October 2011. It was comprised of MoWE, GIZ-Energy Coordination Office (ECO), Ethiopian Electric Agency (EEA), Ethiopian Electric Power Cooperation (EEPCo), Ministry of Agriculture (MoA) and Central Statistics Authority (CSA). When completed, the study will be the second study of the whole energy sector of the country, next to the one conducted by CESEN-ANSALDO Group in the 1980s. According to this recent study, the country has the potential to generate an astounding 60,000 MW from three renewable energy resources. Most of this potential is attributed to hydropower (45,000 MW), 10,000 MW is from wind, and the rest 5000 MW is from geothermal [7]. In addition the study identified the solar energy potential of the country as 5.26 kWh per square meter per day.

The database will enable the generation of a variety of energy maps based on data collected on the supply side of electricity, hydropower, wind, solar, biomass and hydrocarbons. It is believed that the country's national energy map will enable it to attract private investors to engage in the sector by indicating clearly the potential areas for power generation.

Besides national level studies by SWERA and CESEN-ANSALDO Group, some scholars [19–21] tried to estimate wind resource of the country based on the data that has been collected and documented by NMSA of Ethiopia together with data from previous studies of neighboring countries and then conducted a series of analyses to illustrate the general availability of wind energy across Ethiopia. Data used in the first study [20] was collected during the period 1979–1990 from 21 meteorological stations with hourly or 3-hourly readings and 60 stations with monthly means, together with data from 12 stations of previous studies of neighboring countries. The other study by [21] in 1988 used relatively old data; the most recent data used in this study was from 1968–1973 and was recorded only three times a day, at 6:00, 12:00, and 18:00 for 20 locations across the country. The remaining data used in this study was also recorded three times a day at 8:00, 14:00 and 19:00 during the period 1937 to 1940.

For some of the currently ongoing wind farm projects; the German Agency for Technical Cooperation (GTZ) has conducted a number of studies and a series of analysis in wind energy assessment in Ashegoda, Maymekden, Mesobo-Harena, Adama and Gondar regions of Ethiopia from 2004 to 2006 [22–26]. The studies have been performed from taking into account data from the on-site measurement station for two different measurement heights (10 m and 40 m) [22]. To predict the long-term wind speed on site, long-term correlations using the MCP (Measure–Correlate–Predict) method have been performed, using NCEP (US-National Center for Environmental Prediction) reanalysis wind data of a period of 25 years [23,24]. The findings of this correlation were adapted to the measured wind speeds in order to make them long-term representative. The long-term average wind speed for Ashegoda, Maymekden, Mesobo-Harena, Nazreth and Gonder plateau at a height of 40 m above ground are 8.11, 5.7, 6.88, 9.4 and 6 m/s respectively [25,26]. According to the studies, all sites have the highest wind speeds in the dry season and, thus, are complementary to the availability of hydropower. In the rainy season all sites have minimum wind speed. Judging from the wind data, EEPCo is strongly recommended to continue developing the wind energy sector in the studied sites.

Several sporadic attempts were also conducted by different scholars to identify the wind energy resource in Ethiopia for some specific regions. Those studies [27–33] were looking at the wind energy potential as a side bar, i.e. "the role of wind energy for rural development" or the like. In addition, when estimating the wind regime, all these studies relied on meteorological data, which is understandable in the absence of other wind data, carried out particularly for wind energy assessments. As is known, meteorological data could be suitable to give a first hint on the seasonal variation of wind speeds (i.e. higher wind speeds during dry season or in summer etc.). However, they are generally insufficient for the determination of the absolute level of available wind energy on specific site.

4. The current national strategy and policy of the energy sector in Ethiopia

The current energy sector policy of the country aimed a five-fold increase in renewable energy production by the end of 2015, from a current 2052 MW (52 MW added from wind in December 2012) to about 10,000 MW [9] and also targets to export power to neighboring countries since power demand in Ethiopia is constrained by limited consumption due to underdevelopment. To meet the above target the Ethiopian government is aggressively constructing eight wind farms with total capacity of 1116 MW, one geothermal plant with capacity of around 70 MW and a number of hydropower plant projects, including the 1870 MW Gilgel Gibe III dam on the Omo River, the 2000 MW Gilgel Gibe IV dam and the 6000 MW Grand Ethiopian Renaissance Dam on the Blue Nile river [9]. Currently, four wind farms are under construction and one wind farm with capacity of 52 MW power already completed in December 2012.According to EEPCo the longer-term plan is to hit a target of zero carbon emissions by 2025 with hopes that the private sector will play a pivotal role to help meet these goals.

Even though the country has low total installed capacity, Ethiopia is currently undertaking multibillion dollar investments on a number of green energy projects that will see the country become one of Africa's leading exporters of power. According to EEPCo the World Bank is supporting the Ethiopian government plan to export electricity to Kenya, Burundi Tanzania, Ruanda, Uganda and the self-declared autonomous nation of Somaliland [9]. Yemen and Egypt were also added to the list of names that would benefit from the Ethiopian dams. Ethiopia made initial agreement to supply 200 MW to Djibouti, 200 MW to Sudan, and 500 MW to Kenya. Ethiopia has been exporting approximately 80 MW of power capacities for neighbor Djibouti since June 2011 and 100 MW for Sudan since December 2012. However some critics say it is unusual for the country to export power whilst almost half of its own populations are living without electricity.

Power Sector Reform (PSR) in Ethiopia was done in the 1997 by conducting a study that examined the various options for reforming the country's sole national utility, Ethiopian Electric Light and power Authority (EELPA) [34]. Following the PSR, the Ethiopian Government has taken the first essential steps namely: setting up a regulatory agency; Issuing proclamations to change the legal and regulatory framework; Restructuring its public utility, the Ethiopia Electric Light and Power Authority, EELPA (which was an agency under the Ministry of Mines and Energy) to become the Ethiopian Electric Power Corporation (EEPCO), an autonomous public enterprise; and, re-orienting EEPCO's duties and responsibilities on commercial lines [35,36]. In the late 1990s, renewed interest arose in the country to open the power market for Independent power Producers (IPPs) and also to separate the operation and regulatory functions in the power sector. Proclamations and regulations were

issued to this effect [37]. Regulations for the Ethiopia power sector include the following:

- Electricity Proclamation no. 86/1997 [38]: this proclamation established an electricity regulatory agency, Ethiopian Electricity Agency (EEA). The Agency was entrusted to regulate the technical (standards, efficiency, and reliability) and economic (tariffs) operation of the sector. The Agency issues or revokes licenses to generation, transmission and distribution operators.
- Electricity Operations Council of Ministers Regulations no. 49/1999 [39]: this regulation provides guidelines and procedures for electricity sector operators. Technical standards and principles of tariff determination are provided in the regulation.
- Rural Electrification Fund Establishment Proclamation no. 317/2003 [40]: this proclamation established the Rural Electrification Fund (REF) to promote off-grid rural electrification. The REF was to set up to support non-state actors (private companies, cooperatives and other non-government organizations) technically and financially. The REF channels government, lender and grant finance to off-grid operators.
- The amended Investment Proclamation (no. 116/1998) [41]: the Investment Proclamation governs internal and external investment in Ethiopia. The general investment regulations apply also for the energy sector. However, the power sector is dealt with particularly in the Proclamation where foreign investment is limited for certain power generation facilities.

According to the amended Investment Proclamation electricity generation from sources other than hydropower is reserved for the government and local developers. Development of non-hydropower plants larger than 25 MW is left to the government and those below this threshold are open to the local private sector. The government remains the sole operator of the national grid. Electricity generation from hydropower is open to both local and external developers without limit on capacity, Table 8 [41].

Following these proclamations and regulations considerable interest was shown by several companies to supply power to EEPCO. Several Memorandum of Understanding (MOU), have been signed between these potential IPPs and the electricity sector regulator, the Ethiopian electric agency but none have been realized. Since the rationale for IPPs is that they fill government resource gap and that they foster efficiency, their non-engagement is mainly due to due to lack of sufficient capacity demonstration of the potential IPPs and also lack of attractive Power Purchase Agreements (PPAs) by the regulator (EEA) [37].

Despite the enactment of legislations [39,42], strategies and policies to enable power supply by IPPs to the grid, EEPCo dominance as the sole power producer and distributor on the grid continues and expands further. The off-grid market, though theoretically free to developers, is also constrained due to uncertainties regarding EEPCo's grid expansion plans. A few Energy Service Companies (ESCOs) and municipalities run micro-grids in small towns (mainly powered by diesel generators); there are also a few thousand PV home systems. But the combined capacity of these non-EEPCo suppliers is a fraction of EEPCo's SCS system [43].

From 2005 to 2010, the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) [43], was set by the government as a national strategy targeting its energy sector to increase the access rate from 16% (2005) to 50% (2010) by the augmentation of energy generation from 791 MW to 2218 MW and the expansion of the grid to 13,054 km. Improving the efficiency of the existing energy resources and reducing the energy loss from 19.5% to the international average 13.5% were also other targets during the same period of time. With current capacity of 2052 MW from 791 MW in 2005 and current electricity access rate of around 50%, EEPCo believes it is a good achievement.

Both grid and off-grid rural electrification programs are now promoted. The grid based program run by EEPCo is called the Universal Electricity Access Program (UEAP) [44], so far with the addition of 51 MW from the nation's first ever wind farm project, Adama I wind farm, EEPCo has created electricity access for around 50% of the population at the end of 2012, and envisaged to achieve universal access by 2015. The alternate program is for off-grid rural electrification, and it is run by the REF which promotes decentralized, mainly renewable energy technologies such as wind and solar through the private sector and electricity service cooperatives. The UEAP is progressing rapidly and it appears that all as yet non-electrified towns (of more than 1000 households) will be connected to the grid with this program. This leaves only small remote towns, and scattered rural villages for off-grid service. These small towns and rural households can be served with either mini-grids or individual systems.

Ethiopia has signed the Kyoto Protocol and the Environmental Protection Authority (EPA), under the MoWE, was established as the Designated National Authority (DNA), which is the official agency dealing with all Clean Development Mechanism (CDM) projects to follow up the Kyoto Protocol. The CDM does not improve the energy situation directly but it can be an incentive to attract private investors. However, since hydropower, which does not emit CO_2, is the main energy resource in Ethiopia, Certified Emission Reduction (CER) is very low compared to the countries where fossil electric generation is the mainstream power source.

Among the government agencies [45,46], the Ethiopian Environment Protection Authority (EEPA) has the responsibility for the authorization of projects licensed by EEA under federal authority and to monitor implementation and operations. Regional environmental protection agencies have similar authority over projects that are licensed (projects that do not have inter-regional impacts) by the regions.

The regulatory roles of EEA are: to supervise and ensure that the generation, transmission, distribution and sale of electricity in accordance with the Electricity Proclamation no. 86/1997; to determine the quality and standard of electricity services and

Table 8
Limits on capacity of electricity generation for local and external private developers [44].

Power plant	Potential developer	
	Capacity < 25 MW	Capacity > 25 MW
Hydropower	Local, external private and EEPCo	Local, external private and EEPCo
Geothermal	Local private and EEPCo	Only EEPCo
Coal	Local private and EEPCo	Only EEPCo
wind	Local private and EEPCo	Only EEPCo
Solar	Local private and EEPCo	Only EEPCo
Biomass	Local private and EEPCo	Only EEPCo

ensure implementation; to issue certificates of professional competence to electrical contractors; issuing and revoking licenses for the generation, transmission, distribution and sale of electricity; to recommend a tariff and supervise the implementation of the tariff; to cooperate with training institutions in the field of technical development of electricity.

The EEA is striving to fulfill the expansion of efficient, economical electricity supply and equitable distribution. In October 2011, the EEA prepared the Energy and Feed-in Tariff Proclamation [47] that will allow the private sector to supply power to Ethiopia's national grid system. EEA submitted Feed-in Tariff Proclamation to MoWE. The MoWE is to present the draft proclamation to the Council of Ministers. According to EEA, the proclamation sets the tariff rates for IPPs who can generate electricity from different power sources. The maximum rate is set for power generated from geothermal, biomass, baggase (residue left after the extraction of juice from sugar cane) and wind, while the minimum rate is allotted for power generated from hydropower, coal, natural gas and oil shale, Table 9. However, different stakeholders from the private sectors have been complaining about the tariff rates set in the bill claiming that it does not consider the investment cost of generation of power and will not attract investors and also the prices offered are very cheap when compared to other African countries such as Kenya, which some of the stakeholders consider as having an attractive feed in tariff, offers 0.12 dollars for a kilowatt-hour for a firm energy generation from hydro power.

Table 9
Tariff rates set by EEA for IPPs [47].

Power source	Potential developer	
	Minimum Rate per kWh	Maximum rate per kWh
Wind		0.1$
Geothermal		0.1$
Biomass		0.1$
Bagasse		0.1$
coal	0.06$	
Oil shale	0.06$	
Natural gas	0.06$	
Hydropower	0.08$	

Fig. 9. Some of erected wind turbines in Ashegoda wind farm in Ethiopia [9].

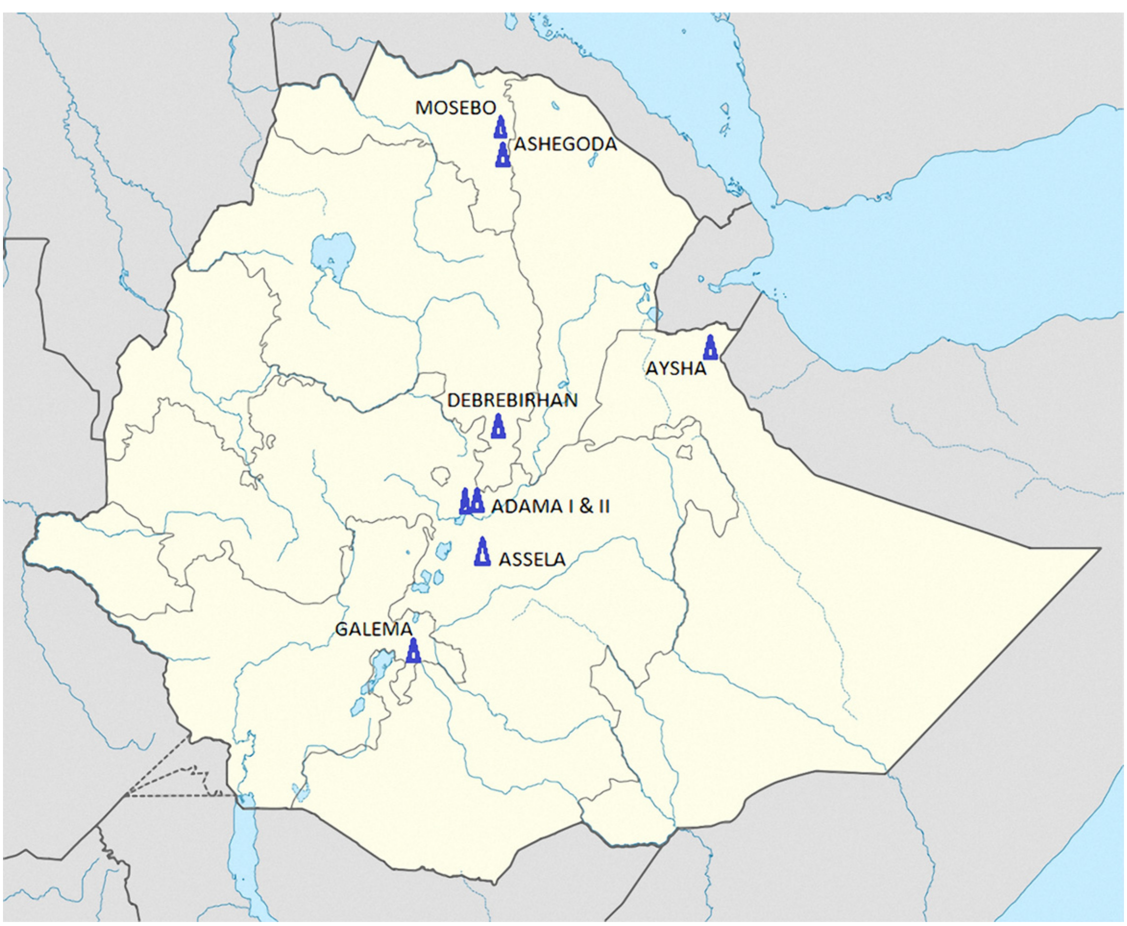

Fig. 8. Ongoing and planned wind farm projects considered within Ethiopia [9].

Up to now, with government subsidy, the EEPCo tariff at the household level is 0.042 dollars per kWh, while charging 0.075 dollars per kWh for commercial purposes which is lowest in Africa [48,49].

Fig. 10. Some of the erected wind turbines in Adama I wind farm in Ethiopia [9].

As mentioned earlier, the current national strategy and policy, according to the growth and transformation plan [6] adopted by the government for the period of 2011 to 2015, is to build a number of wind farms together with big hydropower dams and working toward increasing its renewable energy output five-fold in the next five years. Currently the Ministry of Water and Energy is the policy making body of the government. The MoWE formulates energy sector policies and supervise their implementation when approved. Recently, with the aim of constructing eight wind farms with total capacity of 1116 MW, wind energy resource development together with hydropower plants are the top priorities of all renewable energy resources that are given attention in Ethiopia [9]. Currently, four wind farms are under construction and one wind farm with capacity of 52 MW power already completed in December 2012.

5. Ongoing renewable energy projects in Ethiopia

Wind energy application in Ethiopia has been limited to water pumping in the past. There is now, however, definite plan to exploit wind for power production. With the aim of diversifying the energy sources, the Ethiopian government is constructing a number of wind farms with total capacity of 1116 MW. It was mentioned that according

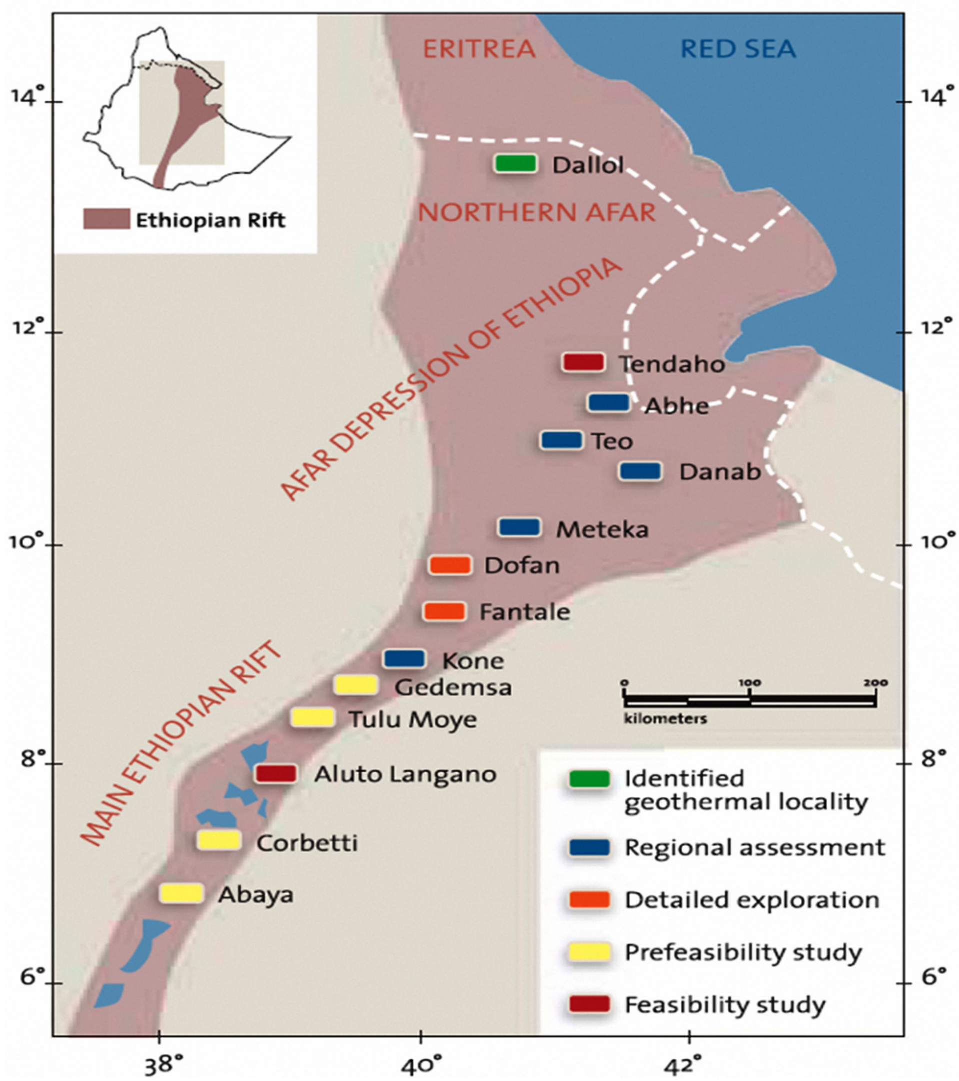

Fig. 11. Ongoing and planned geothermal projects considered within Ethiopia [53].

to the growth and transformation plan adopted by the government for the period of 2011 to 2015, EEPCo has planned to build eight wind farms [6]. Those wind farms are the 120 MW Ashegoda wind power plant in Tigre region north of the country, the 300 MW Aysha wind farm near the Djibouti border, the 100 MW Debre Birhan wind farm north of Addis Ababa, the 100 MW Assela wind power project southeast of the capital, 52 MW Adama I wind farm and the 153 MW Adama II wind power project south of the capital, the 250 MW Galema I wind power project south of the capital and the 42 MW Mesebo-Harena wind farm in Tigre region north of the country [9]. Ongoing and planned wind farm projects considered within Ethiopia are shown in Fig. 8 [9].

Currently, four wind farms are under construction and the 52 MW Adama I wind farm already completed in December 2012. The French wind turbine maker Vergnet started constructing the 120 MW Ashegoda wind power plant in 2008 with a total cost of $286 million. VERGNET GEV HP 1 MW wind turbines are used to construct the wind power plant. Those turbines adapted to remote regions where conventional wind turbines cannot be installed due to difficult access conditions, limited infrastructures, lack of big cranes and unstable grid [50]. In February 2011, EEPCO announced that Ashegoda Wind Power Plant already started producing 30 MW. This project is expected to be completed by the end of 2013. Some of the erected wind turbines in Ashegoda wind farm are shown in Fig. 9 [9].

The 52 MW Adama I wind farm which was under construction by Hydro China-CGCOC [9] with a fund of 117 million US dollar loan from the Export-Import Bank of China, completed in December 2012 and now it is producing 52 MW. Some of the erected wind turbines in Adama I wind farm are shown in Fig. 10 [9].

The Aysha wind farm project will add 300 MW clean wind energy to the Ethiopian electricity grid [51]. The site for the wind farm is located in the east of Ethiopia close to the borders of Djibouti and Somaliland. This eases the future power export to the two countries. The erection of the first turbines and initial power production were started by the end of 2011. Completed construction of the project and full production of the wind farm is expected to be reached till 2015 [51].

The rest five wind farm projects such as the 100 MW Assela wind power project southeast of the capital, the 153 MW Adama II wind power project south of the capital and the 100 MW Debre Birhan wind farm north of Addis Ababa, the 250 MW Galema I wind power project and the 42 MW Mesebo-Harena wind farm are firmly underway even though all are under their initial stage [9]. According to EEPCo's plan, all the eight wind farm projects are expected to be completed by the end of 2015.

For Ethiopia wind constitutes an important alternative source of power generation to hydropower because winds in Ethiopia are especially strong in the dry season, while hydropower potential is dropping to a low point towards the start of the annual rainy season. This fact makes wind power an even higher value contribution to the energy mix from a risk management point of view.

Besides the ongoing wind energy projects, with potential of producing up to 5000 MW electric power from geothermal, Ethiopia aspires to utilize its geothermal energy resource [52]. The Aluto-Langano geothermal power plant (70 MW) is currently under construction and also the Tendaho geothermal plant is in progress to create 5 MW soon. Ethiopia is among the few countries in Africa with a significant amount of geothermal resources [53]. These resources are found scattered throughout the Ethiopian Rift valley and in the Afar depression, which are both part of the Great East African Rift System. Ethiopia launched a long term geothermal exploration undertaking in 1969. Over the years, a good inventory of the potential target areas has been built up and about 16 geothermal prospects are judged as having potential for electricity generation Fig. 11 [53].

Ethiopia considers itself as the powerhouse of Africa due to its high hydropower potential. But so far only a 4% of this potential has been harnessed. In 2011 less than 50% of Ethiopians had access

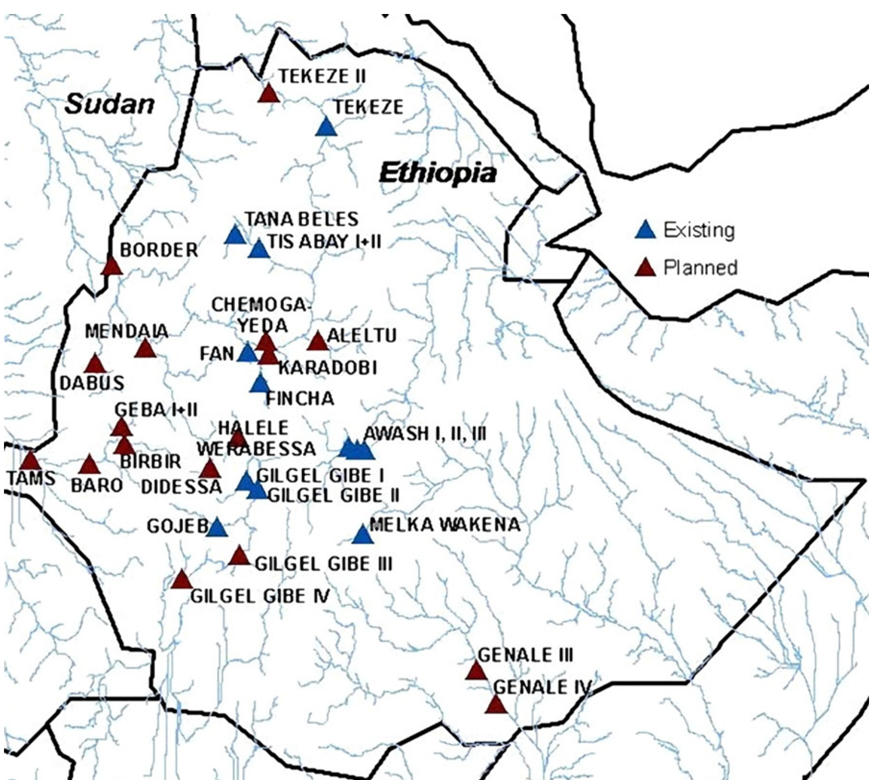

Fig. 12. Existing and planned hydropower projects considered within Ethiopia [54,55].

to electricity. In order to overcome this situation, besides the wind farm projects mentioned above, many hydroelectric projects, including the 1870 MW Gilgel Gibe III dam and the 6000 MW Grand Ethiopian Renaissance dam are under construction. Many of those dams are multi-purpose dams that are also designed to provide water for irrigation and flood control. However, hydropower is expected to be the main benefit of the dams [54]. Some of the Existing and planned hydropower projects are shown in Fig. 12 [54,55].

Those ongoing wind, geothermal and hydropower projects are parts of Ethiopia's strategy to become the region's leading producer of clean renewable energy. The ongoing and planned wind farm, geothermal and hydropower projects in Ethiopia and their capacities are shown in Table 10 [9,55].

When we look on the country's electricity generation plan, about 94% of the electricity generation is to be supplied by hydropower, 5% by wind and the rest around 2% by geothermal. This is rational considering the facts that Ethiopia is rich in water resources and hydropower is relatively cheap. However, the rainfall in Ethiopia varies considerably from year to year and therefore, over dependence on hydropower may make the energy supply very unstable. More diversification of energy resources is essential for sustainable development of the sector. As mentioned, Ethiopia receives high solar energy, with an average potential of 5.26 kWh per square meter per day but the Ethiopian government is not utilizing its solar potential. The reason is that solar power is by far the most expensive renewable source to produce electricity, although increasing efficiency and longer lifespan of photovoltaic panels together with reduced production costs could make this source of energy more competitive. Generally when the energy mix in Ethiopia is considered, hydropower takes the lion's share in contrast to many countries which rely on coal, gas or nuclear. So far due to relatively low energy consumption in the country this may not pose issue but in the future, with consumption increases it will be interesting to see if this kind of energy mix will be sustainable.

Table 10
Ongoing and planned wind farm, geothermal and hydropower projects [9,55].

		Capacity (MW)				Commissioning year
		Wind	Geothermal	Hydro	Total	
1	Ashegoda wind farm	120			120	2014
2	Aysha wind farm	300			300	2015
3	Adama I wind farm	51			51	2012
4	Adama II wind farm	153			153	2015
5	Debre birhan wind farm	100			100	2015
6	Assela wind farm	100			100	2015
7	Galema I wind farm	250			250	2020
8	Mosebo Harena	42			42	2020
9	Aluto Langano		70		70	2015
10	Tendaho		100		100	2018
11	Corbetti		75		75	2018
12	Abaya		100		40	2018
13	Tutlu Moya		40		40	2018
14	Dofan		60		60	2018
15	Hidassie			6000	6000	2015
16	Fincha Amerti Nesh			97	97	2015
17	Gilgel gibe III			1870	1870	2015
18	Chemoga Yeda I			162	162	2015
19	Chemoga Yeda II			118	118	2015
20	Halele			96	96	2015
21	Worabesa			326	326	2015
22	Gilgel Gibe IV			1472	1472	2015
23	Geba II			157	157	2020
24	Genale Dawa III			254	254	2020
25	Geba I			215	215	2020
26	Genale Dawa IV			246	246	2020
27	Gilgel Gibe V			660	660	2020
28	Tekeze II			450	450	2020
29	Mendaya			2000	2000	2020
30	Beko Abo			2100	2100	2020
31	Wabi Shebele 18th			87	87	2020
32	Dedessa			613	613	2020
33	Birbir			467	467	2020
34	Dabus			425	425	2020
35	Tams			1000	1000	2020
36	Border			800	800	2020
37	Kara Dodi			1600	1600	2025
38	Genale Dawa V			100	100	2020
Sub total		1116	70	21,315	22,501	

6. Conclusion

Even though the Ethiopian electricity generation capacity is low, at present, the country is determined to be able to develop, transform and utilize its energy resources for optimal economic development. With electricity access rate less than 50%, so far the most of rural areas of the country is heavily dependent on traditional fuels consisting mainly of wood for cooking and heating. Considering this fact Ethiopian government is aggressively constructing a considerable number of wind and hydropower plants.

As studies found out and suggested, government support and availability of large unpopulated areas in the country like Ethiopia make attractive the use of those lands for siting large wind farms. There is also a need to formulate and implement a long-term plan to promote wind energy development together with other renewable energy sources, and the introduction of innovative financing mechanisms for their support. Providing attractive duty tax reductions and other incentives to support renewable energy technology development would also aid in its dissemination.

The Ethiopian power sector is over dependant on hydropower. The country need to diversify its energy sector and keep looking for other energy sources such as wind, geothermal and solar because its extreme hydropower dependence may leave its power sector vulnerable to drought, an increasingly risky scenario due to climate change. Falling reservoir levels may affect Ethiopian electricity consumers and export revenues. It is also advisable that, policy-makers revise the existing national energy policy to overcome such scenario and look for a diversified energy sector development especially to look on the geothermal sector since it is available substantially in the country and also is one of the most economical for electricity production. With recent technological advancements and price reductions in capital cost, solar power is gaining more acceptances and is becoming an increasingly cost-effective and clean alternative to conventional energy sources. Hence, it is also advisable for the country to develop its solar energy.

If Ethiopia carries out its current energy development plans and revise the existing national energy policy that means allowing domestic and foreign investors to produce power from all kind of energy sources without limit on the capacity, the country will be able to attract more investors in renewable energy sector. The application of renewable energy technologies has also the potential to alleviate many of the problems that face Ethiopia especially in electrifying remote towns, and scattered rural villages using mini-grid system.

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